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Parametric Analysis and Quality Improvement of Mould Filling Process for the Manufacturing of a Car Side Mirror Cover: A Case Study

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ABSTRACT

The aim of this research paper is to reduce the defects rate and process variation during production of car side mirror plastic cover. The main purpose of this research study is first one to recognize the root cause analysis of quality problems as well as other surface marks on car side mirror plastic cover. The second purpose is to implement sigma with DMAIC to improve the quality of car side mirror plastic cover. A plastics industry in Pakistan has many quality problems during the production of car side mirror plastic cover such as black dots, air bubbles, flow marks and part hard fitting. Due to process variation, non-conformity increases and poor-quality parts are produced. The industry faces high percentage of wastage, production cost and low customer's satisfaction due to low quality of mould part. The major rejection of moulded part is found due to hard fitting, black dots, air bubbles and flow marks. The Six-sigma with DMAIC (Define, Measure, Analysis, Improve, and Control) was applied to overcome these quality problems and process variation. DMAIC is an engineering technique that can be used in service and production which requires a practical solution. This improvement technique is applied on injection moulding machine 360 tone Tederic manufactured by china Model 2005 which has major rejection rate. This machine had 35% rejection of total rejection before improvement. After development, it reduced to 16%. Four major quality problems are removed and increased the quality level and customer's satisfaction. The reduction of rejection rate and wastage has saved company time, money and improved company sigma level.

1. Introduction

Manufacturing is a method to produce something new for the comfort human being. It is a process to convert a material into useable products with high value. The materials which are used in industry are categorized into four main types: polymers, composites, ceramics and metals. Polymers are further divided into two types: rubber and plastics. Plastics are further categorized into two types, which are thermo sets and thermoplastics. Thermoplastics have repeatedly cooling and heating cycles without undergoing degradation. This property makes thermoplastics suitable for usage in injection moulding process [1]. Plastic injection moulding is a process in which molten plastic material is injected

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into mould cavity, under high pressure, where it solidifies. Then, the mould is opened and moulded part is removed from the mould cavity [2]. Any process may have variation. Defected parts and wastes are produced when this variation crosses a certain limit. Six-sigma with DMAIC is an engineering technique that is used to decrease the variation and minimize the possible wastage [3]. Six-sigma is an engineering technique which is applied to improve an injection moulding process. These techniques can minimize quality defects in plastics injection moulding process. It explains how a process can vary from its standard and how it can be improved. The basic purpose of six- sigma is to improve six standard deviances concerning target and the specification limit [4]. Anything which does not meet the standard is reflected as defected. This defect is calculated by defects per million opportunities (DPMO) or parts per million (PPM). Six-sigma is implemented to prevent defects rather than defective. Quality of plastics injection moulding could be improved by six-sigma techniques which reduce the variance in process [5]. This research study is based to understand and look after the critical aims and objectives for quality improvement of plastics products in injection moulding process. Most of the study is based on theoretical and practical experiments [6]. Using six-sigma the root cause of defect could be identified and removed. Six-sigma integrates both qualitative and quantitative tools that is statistical process Pareto chart, histogram, hypothesis test, control (SPC) charts, analysis of measurement system, Ishikawa diagram and worksheet to attain the preferred goals [7]. An extensive study of six-sigma has led to increase interests of both statistical and managerial tools [8].It is a unique method that provides a set of techniques to organization to improve quality of plastic products and enhances business growth. The focus of six-sigma is decreasing variance in product quality features to a level where defects are prominent [9]. Six-sigma is a philosophy which is implemented about four decades ago. It is not only applicable in plastics products but also involve in any processes like transaction, business operation such as research and development, sales and delivery process. It is also concern in administration and other areas in which directly effects the customer [10].The six sigma is a philosophy that provides step-by-step quality improvement methodology. It uses statistical methods to reduce variability [11]. Six- sigma is quality improvement tool that aimed to improve production process and management system by focusing on reducing variances and reduce product defects [12]. All over the world, six-sigma today is concerned only in extent of quality improvement strategy to overall business for number of companies. In 1986, Bill Smith gave concept of six-sigma to improve quality of products [13]. Six-sigma is one of the most effective innovation improvement techniques which have undeviating influence on organization progress. By using these techniques, a plastics company can enhance its growth and values in market [14]. Six-sigma DMAIC is a philosophy which can improve plastics quality and eliminate the defects of products. It is a quality improvement program that can reduce products wastage, lead time and customer complaints and cost saving. This method increases product quality and market competency [15]. In general, rejection and wastage cannot be ignored in an organization. To identify the root cause of these problems and to minimize these wastage and rejection, a scientific and organized approach has been applied that is adopted for last few decades [16][17]. This technique can be applied in every field of business that improves the quality by analyzing data to find root cause of quality problems and is applied to control these problems. It is a quality improvement strategy used to improve profitability of products. It is used to drive out waste in the plastics moulding process and to improve the efficiency of all operations that meets customer’s requirements and expectations. These techniques refers to a process in which the rage between nearest specific limit and mean of process quality is at least six times the standard deviation of the process [18][19]. According to Pranav-Bharara (2018), six-sigma is myriad tool and methodology which is used to improve capability of process. Moreover, it is a popular approach used by managements [20][21][22]. A manufacturing company needs to improve the quality of process by applying such a nice technique to reduce the defects rate. Applying six-sigma with DMAIC, quality of a car side mirror would be improved in manufacturing company in Pakistan in injection moulding process.

Figure 1 Problematic Parts

Figure 2 Injection Moulding Machine (Tederic 360)

2. Methodology

Quality of products in injection moulding process was improved by DMAIC methodology. The DMAIC stands for Define, Measure, Analyze, Improve, and Control. The DMAIC is a statistical technical approach to quality management and hence DMAIC is used to improve the quality of plastics in injection moulding process[23].

2.1. Define Phase-DMAIC

Define phase is the first phase of DMAIC methodology. In this phase, all circumstances should be defined before process investigation. These circumstances are defined by describing SIPOC (Supplier, Inputs, Process, output, and customer) diagram. In this phase, problems along with inputs

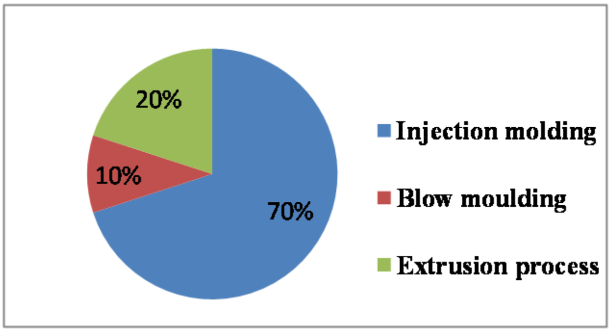

Figure 3 Thermosole Industry Sale Percentage

and outputs of system are stated. It also explains customer requirements, goal of project and objective. Figure 3 illustrates that 70% of company sale is contributed by injection moulding process. Thus, quality improvement in injection moulding brings a huge profit in company sales. In plastics industry, highest percentage of rejection was car side mirror plastic cover. Consequently, the limit of this project was focused on improvement in quality of this part. The scope and goal of the research was to minimize defect rate of car side mirror plastic cover fitting and black dots up to 60%. Moreover, the construction of SIPOC diagram was to identify related components of the project. This diagram provides overview and The scope and goal of the research was to general information of project. SIPOC diagram is shown in Figure 4

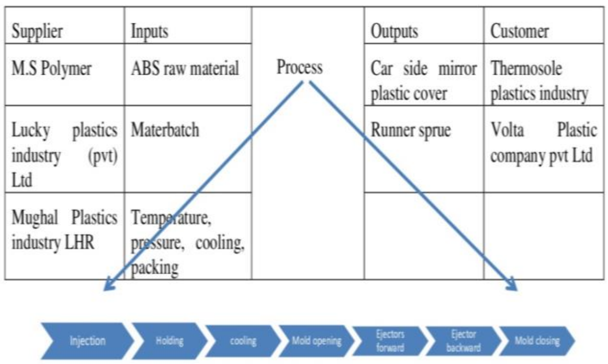

Figure 4 SIPOC Diagram

In this phase, SIPOC is used to identify stakeholders and come to an agreement on boundary of the project. Stakeholders are considered who gets affected by the project or anyone that benefits from project.

2.2. Calculation of Current Rejection

Table 1 on production line rejection

Total parts produced: 5000				
Part name/No.	**On production line rejection**	**On production line × 10^3**	**Percentage**	**Acc.**
Car side mirror cover	1650	1.650	33	33
Plate 5052	1230	1.230	24.6	57.6
Panel city	1052	1.052	21.04	78.64
Trim wheel city	830	0.830	16.6	95.24
Others	238	0.238	4.76	100

Table 1 shows rejection data of injection moulding at 360 tonnes for the month of January 2020. This rejection was uppermost rejection in comparison to preceding month rejection. In this rejection car side mirror cover rejection is highest rejection that is 1650 units and this is 33% of total rejection. Pareto diagram is shown in Figure 3 which shows on-line rejection for the particular part. Car side mirror is taken as research element because it has uppermost rejection rate.

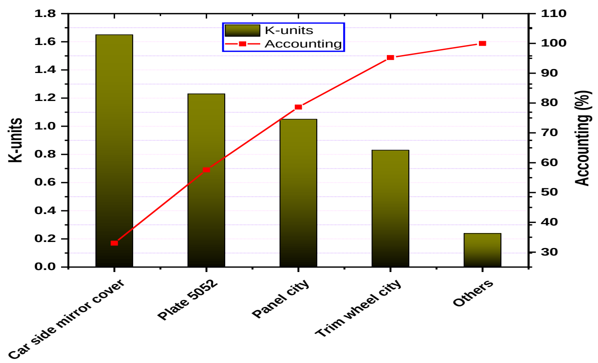

Figure 5 on- line rejection for particular part

2.3. Measure phase-DMAIC

In this phase defects per million opportunities (DPMO) is calculated. For this purpose, data was collected continuously for four months from February to May 2020. In this study, production of four machines is considered. This output data was collected from on-line rejection that produced on 360 tone injection moulding machine. This data was used to focus on the production of car side mirror cover. It helped to find out root cause of problem which is concerned to this part. Since same part is produced on all machines, the data was collected from every machine. The defects per million opportunities (DPMO) were calculated by using this data for each month. Sigma level, total output, DPMO, reject quantity for each month from February to May 2020 is shown in table 2.

Formula used to calculate sigma level

- Total rejection =R
- Total pieces manufactured=P
- Defect per unit(DPU) =R/P
- Total critical to quality(CTQ) =O
- Defects per opportunity (DPO) =DPU/CTQ
- Defects per million opportunity (DPMO) =DPO×1000000
- Sigma level

$$(\sigma) = 0.8406 + \sqrt{29.37 - 2.221 \ln DPMO}$$

Calculation of sigma level for February 2020

- Total parts manufactured
  P = 30,000
- Total rejection
  R = 432
- Total CTQ
  O = 5
- DPU $\frac{R}{P} = 0.0144$
- DPO $\frac{DPU}{CTQ} = 0.00288$
- DPMO DPO × 1000000 = 2880
- Sigma level

$$\sigma = 0.8406 + \sqrt{29.37 - 2.221\ln(2880)}$$
$$= 4.2580$$

Similarly, we can calculate DPMO and sigma level for other months.

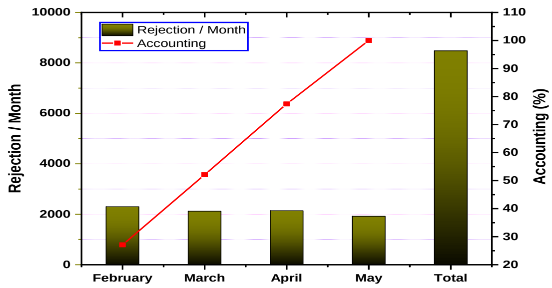

Figure 6 In-line rejections from month February to May 2020

Table 2 Sigma level and total output

		Machine No.						
Month	**Output**	**JSW**	**Tederic**	**Engel**	**Husky**	**Total rejection/ month**	**DPMO**	**Sigma level**
February	30,000	59	198	90	85	432	2880	4.2580
March	30,000	54	187	80	80	398	2656.9	4.2840
April	30,000	60	179	82	80	401	2679.44	4.2813
May	30,000	38	180	68	75	361	2405.11	4.3160
Total	**120,000**	**211**	**744**	**320**	**320**	**1592**		

Figure 2 shows a bar graph which was constructed to show reject quantity for each month. In February 2020, upper most rejection was recognized in the meantime for other months the data collected shows minor variations. Table 2 shows sigma level for each month based on data and illustrated in figure 4. Figure 7 explains sigma level from month of February to May 2020. For entire process, mean sigma level 4.2884 was calculated. In the month of May 2020, 4.3160 highest sigma level was calculated and lowest was recorded as 4.2580 in month of February 2020. Since lowest sigma level has recorded in the month of February 2020, our concern with this month of February 2020 for research study. To identify the root cause of the problem which contributes to uppermost rejection of the part, this data will be used.

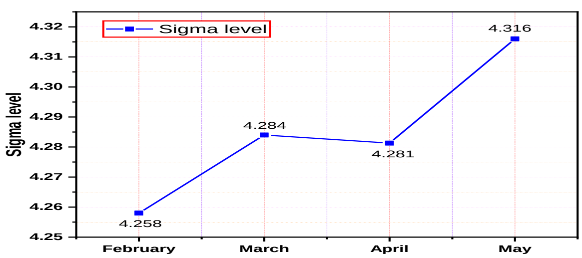

Figure 7 Sigma level for February to May 2020

2.4. Analyses Phase-DMAIC

In analyses phase root cause of hard fitting and black specks is found out which are appeared on the parts produced. The main purpose of analyse phase is to identify the problems and give awareness how to eliminate these defects. A Fishbone diagram which is also known as cause and effect diagram or Ishikawa diagram is constructed to identify the root cause of the problem. Fishbone diagram is constructed to expedite the root cause of defects on parts produced. It is illustrated in figure 8.

Table 3 shows data of defective part for moth of February 2020. Figure 7 shows Pareto diagram based on data of defective part. As discussed before, there are four machines which produce same part that is car side mirror cover. The data was collected from all machines. The machine Tederic has major contribution to the highest rejection rate. Table 3 shows types of different defects which are usually appeared on plastics injection moulded parts. In table 3, major defects are black dots which contribute 35% of total defects and hard fitting contributes 20% of total defects due to which parts are rejected. The comparison among machines defected data shows, hard fitting and black dots are still contribute highest rejection rate. In case of machines, Tederic machine contributes black dots and hard fitting highest defects as compared to other machines. Since Tederic machine shows highest rejection rate, its data is used to track down the root cause of hard fitting and black dots. This analysed data is used as a reference for other machines.

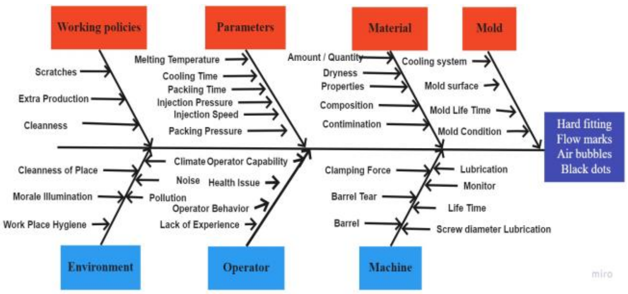

Figure 8 Fishbone or Ishikawa Diagram

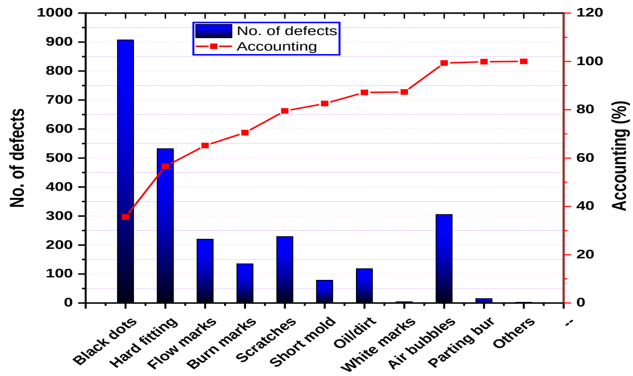

Figure 9 Rejection data for month February 2020

Table 3 Rejection data for the month of February 2020

	Machine number						
Defects	**JSW**	**Tederic**	**Engel**	**Husky**	**Sub Total defects**	**Percentage**	**Acc.**
Black dots	35	340	270	262	907	35.6	35.6
Hard fitting	2	142	122	266	532	20.9	56.5
Flow marks	0	102	98	20	220	8.6	65.2
Burn marks	15	23	97	0	135	5.3	70.5
Scratches	5	65	77	82	229	9.0	79.5
Short mold	3	62	8	5	78	3.1	82.6
Oil/dirt	12	48	34	9	103	4.0	86.6
White marks	0	0	4	0	4	0.2	86.8
Air bubbles	45	90	105	65	305	12.0	98.7
Parting bur	2	6	7	0	15	0.6	99.3
Others	2	15	0	0	17	0.7	100.0
Total	**121**	**893**	**822**	**709**	**2545**		

2.4.1. Root Cause Analysis for Black Dots

In root cause of black dots there are five major factors which are responsible for black dots as following material, method, environment, operator and machine. Machine is one of the factors which must be responsible for black dots. It is possible that black dots that appear on moulded parts are due to machine contribution. For example, improper working parameters setting, it causes carbonized screw. Damaged barrel or screw is also responsible for black dots. The root cause of material inhibition or degradation is a pitted screw or cracked injection cylinder. Finally, black dots appear on the surface of plastic moulded parts because of melt stream of this degraded material. Contamination from lubrication may also contribute to black dots. Lubrication leakage from ejector pins, cams and slides into mould cavity can also be contaminated the material of part that appears as black dots on the surface of part. Aging machine may also contribute to black dots on surface of moulded part. Improper maintenance of machine is also the main reason of black dots because

desire output may not be achieved without proper maintenance of machine. It affects the performance of machine which leads to surface marks and other major defects.
Inexperience and untrained operator causes more defects. The possibilities of defects increase when instructions or leader is not followed. When inexperienced and untrained operator operates the machine then number of defects will increase. Work technique is one of the most important factors that is root cause of defects. This was observed that untrained operator having incorrect technique to set parameters of machine, just followed the instructions to operate machine. As a result, untrained operator can lead to rejection and black dots.

2.4.2. Root Cause Analysis for Hard Fitting

The analysis by fishbone or Ishikawa diagram, the most critical causes were chosen and they were more analysed further. They were revolved to be: contamination of material, working parameters, mould temperature, dryness of material, environment, material properties, surface of mould, proper filling of material, cooling in mould, cycle time, cleanness of mould, operator's training and behaviour with health. Deviation from standard operating procedure (SOP) or method for particular process leads to wrong machine setting or operation parameters. Major defect may base upon following causes as shown in figure 10.

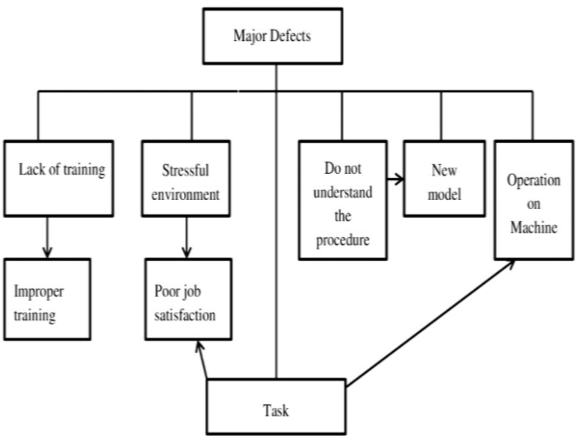

Figure 10 Major defects based on possible cause

2.5. Improve phase-DMAIC

Improve phase is fourth phase of DMAIC methodology. After collecting we analyzed the data, the major defects were found hard fitting and black dots which were root cause of quality problems of moulded parts. Now we are moving onto improve phase in which a possible solution is produced, selection of better solution, assessment of solution and calculate the quality improvement in term of sigma level. The root causes of major defects were identified in analyses phase.

2.5.1. Improvement phase for black dots

Here highly recommended suggestions to remove black dots from moulded part surface are cleaning of barrel and screw of injection moulding machine with cleaning agent.
Before cleaning, the injection screw that is used to mould the car side mirror cover was carbonized. This screw can be cleaned by using sand paper or cleaning agent. Due to overheating, material powder or dirt was identified as carbonization in the barrel. Burnt material stuck on screw which released slowly during every time of injection and appeared as black dots on the surface of car side mirror cover.
It was observed that machine is not cleaned regularly and properly where a material scrape stuck with hydraulic unit area and tie bar. These scrape mix with part material which produces black dots and other defects on the surface of moulded part. It is suggested that after proper cleaning of machine, it should be covered with plastic or polythene to make sure no dust or dirt affects the machine condition. Moreover, resin should also be safe and covered so that no foreign particle mixes with resin which leads to black dots and other defects. Before operation, machine hoper and barrel should be free from other material.
Reduce downtime and minimize scrape to enhance productivity and they save resin from wastage. Purging of machine by small amount of material can also reduce major defects on moulded part. It is experimentally observed that purging with a little amount of water in resin is also very affective to clean the barrel and injection screw of machine. Part quality will be improved and rejection rate will be reduced by acting upon these suggestions and the same time sigma level will also be enhanced.

2.5.2. Improved Phase for Hard Fitting

Now we have to improve quality of molded part that was rejected due to hard fitting. We have identified root cause of hard fitting in analyses phase. In analyses phase, the root cause of hard fitting was identified to be the working parameters. Design of experiment (DOE) can be used to adjust these working parameters. First of all, we need to decrease number of working parameters before DOE implementation and find out which parameter is the most critical factor used in DOE. To identify key input variables cause and effect matrix was used to improve output variables in process. The relationship between input and output variables is shown in figure 9. It was found from cause and effect matrix that nine input variables were included and only three out of nine as well as one output variable will be tested through DOE. These three input variables were melting temperature, injection speed and injection pressure along with number of defects was output variable. After choosing of input and associated output variables, we selected factorial design of experiment (DOE). By Montgomery 2005, it is a method which is used to study and find out relationship among input factors and output of a process usually denoted by 2^k. Here k is factors which affect the process and 2 is factor level. We conducted 2^3 full factorial design of experiment (DOE) according to our factors from cause-and-effect matrix. Following table 3 shows factors and their levels. The collected data was analysed on injection moulding machine of 360 tonne. Each factor level was adjusted on machine panel and made parameter sheet for further production at the same machine.

Table 4 factor and their levels

Factors	levels	
	Low	High
Injection pressure (bar)	162	174
Injection speed (%)	5	11
Melting Temperature (^{0}C)	178	187

Now we desired to measure improvement after improvement and execution of action plans that were made and compared with baseline. We counted and noted the types of defects which occurred during process. These effects are shown in bar chart in figure 10. After improvement, again we calculated DPMO and sigma level in **June 2020** which is shown in table 7. The DPMO is reduced from 2879.9 to 1102 while the sigma level increased from 4.2580 to 4.5570 as compared to the month of **February 2020**.

Table 5 Action Plane

RPN	Failure Mode	Action plane
84	Insufficient amount of material inserted	Make a plane to check material in machine hoper
140	Cleanness of mould	Make a schedule to clean the mould
160	Behaviour of operator	Assign penalties and rewarding
560	Dryness of material	Dry material by using drier

Table 6 Cause and Effect Matric

Output variables (Ys) (Horizontal axis)	Thickness	Weight	Cycle time	No. of defects	Weighted score(X)	%age	Order	Status
Injection pressure	8	4	9	8	176	19.81	3	Critical
Injection speed	8	9	9	8	201	22.6	2	Critical
Contamination of material	0	0	0	4	36	4.05	8	Removed
Packing time	2	2	2	2	48	5.4	7	Removed
Clamping force	0	2	0	0	10	1.1	9	Removed
cooling time	4	2	2	2	60	6.8	5	Removed
Melting temperature	9	9	9	9	216	24.3	1	Critical
Injection pressure	8	4	9	8	176	19.81	3	Critical
Total	36	38	35	38	888			

After improvement of sigma level, the comparison between part rejections, percentage of part rejection and DPMO and sigma level was made as given below

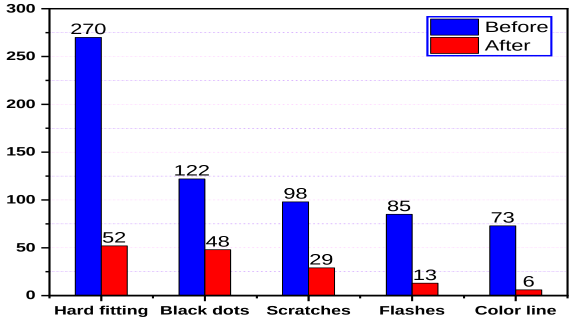

Figure 11 after and before improvement

Table 7 Results after and before Improvements

Car side mirror cover	After	Before
Rejected per day	18	72
Rejected percentage (%)	9	17
DPMO	1102	2879.9
Sigma level	4.5577	4.2580

2.6. Control Phase-DMAIC

The main purpose of this phase is to ensure improvement that could be maintained and sustainable henceforth. Following activities and improvements that can be applied to improve the processes are: Making a checklist sheet for maintenance that would be a reference to monitoring the production process in future. In order to reduce the product defects due to machining factors, the subsequent control is to observe performance and maintenance of machine periodically and intensively. Improving work inspection to reduce the defects produced by human factors and expands work supervision. It would be achieved by discipline leader of workers to reduce the product defects. To achieve process improvement, make sure training of work force to improve their abilities and skills. Fix work stations and environment. This control could be done by closing the doors of crusher machine rooms and installing silencer to reduce the level of noise produced during rework process. This control can also be done by improving work stations of operator so that worker or operator can work comfortably and safely. This improvement can be prevented the manifestation of occupational diseases.

3. Conclusion

- In this study, six sigma DMAIC was successfully applied to a plastics industry to improve quality in injection moulding process.
- DMAIC technique was used to find out root cause of defects and tackle these poor quality problems. We concluded that these poor quality products affected the company reputation time, money and efforts are lost when poor quality product is wasted, recycled and reworked.
- Moulded part is selected which has highest rejection rate that was turned to be car side mirror cover in injection moulding process. DPMO, sigma level and current performance of company are calculated after improvement.
- An Ishikawa of Fishbone diagram was constructed to find out root cause of defects.
- After improvement, process variation significantly reduced and quality level improved more 50% which leads to save company time, cost and build more customer satisfaction level.
- To eliminate black dots, clean barrel and screw of injection machine using cleaning agent. Use sand paper to remove burnt material because of overheating which is carbonized in barrel.
- This overheated material will stick with screw and released at each of injection and appeared as black dots on the surface of part. Design of experiment (DOE) was used to find out working parameters which would produce number of defects that were injection speed, melting temperature and injection pressure.
- The DPMO was reduced from 2879.9 to 1102 and Sigma level was increased from 4.2580 to 4.5570. This improvement was considered more than 50% and action plan was given to company for continuous process improvement.

- The improvement that we made will be beneficial to company and it will enhance profit of company. It will also increase overall performance of injection moulding process.
- Area of the moulding should be neat and clean in order of make good product.
- Worker and machine operator should be well trained who understand the precautions and working SOPs.
- Enhance incentives of the labour to get more quality work.

Precautions for working area

Following precautions necessary to get good quality product;

- Working area should be clean so that no dust particles or material mix with moulded part material.
- Machine operator and all related persons must be trained.
- Special quality improvement session should be conducted in industry to introduce quality improvement techniques.
- Quality related sheets with quality improvement sign should be displayed in working area.
- After manufacturing of part, they should be proper wrapped with polythen and cartons.
- Check hard fitting of moulded part fixtures to ensure their fittings.
- Material before moulding should be proper dried so that no sink or other surface defects should not be encountered.
- Apply check sheets to ensure quality.
- Material handling and maintenance of machine should be proper before moulding so that no lubrication and contamination is added to moulding material.
- All these quality should be adopted strictly so that the quality of production fulfils requirements of customers.

Some recommendation

The researchers offer some recommendations for improvement.

- Improving work stations and environment.
- Increasing inspection and work supervision to improve production quality.
- To monitor production process, create maintenance checklist sheet.
- Assign reward and penalty to improve process.
- Make sure proper training of operators and workers.

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